range -- then there might be a long standoff in the advisory committee process. A divided advisory committee report could lead to considerable delay in FCC adoption of a standard.

Realistically, if the FCC had a $10 million per year testing budget and was run by a single administrator who answered only to the President, and all the possible systems could be tested today, I would expect the FCC to take two to three years to set a standard. The current FCC, with essentially no testing budget, committee decision making at the top, and answerable to Congress and the President, would take the better part of a decade to choose PCS standards.

4.1.8 Standards Selection and a Nationwide Licensee

A nationwide licensee controlling somewhere between 18 and 30 MHz of spectrum would constitute in itself a large enough customer to induce firms to develop specialized equipment and to bring new designs to the market. If such a firm chose a technology and committed to that technology, it could build a viable business.

Such a firm would have the appropriate incentives for standards choice. Delay in setting a standard would keep it out of the market. Choice of an inefficient standard would reduce the competitiveness of its offerings and its chances for marketplace success.

If a nationwide licensee discovers that it has chosen the wrong standard, say, because a new system design comes along that makes the original choice obsolete, it can abandon the original choice and move to the new technology. The original choice can be modified outside the political process.

Note also that such a national service provider may stimulate the standards adoption process -- that firm's standards choice is a powerful signal to the market. But, this choice is not imposed on anyone else. If the firm does make a mistake, other firms can choose other technologies and offer consumers the alternative.

4.1.9 Conclusions on Standards Choice

Given the environment (many disparate standards, substantial legal and political constraints on the FCC, lack of the FCC budget for internal or contract testing), it is hard to imagine the FCC selection of a standard for PCS being anything other than vastly inferior to the alternative of leaving the PCS standards selection process to the market if that market includes a few nationwide licensees.

4.2 Minimizing Transaction Costs of Frequency Coordination

Each PCS operator will have to coordinate his or her use of radio equipment with operators serving nearby geographic regions. Figure 5 displays an area divided into nine geographic regions. Region 5 borders eight other regions. Radio transmissions originating near the edge of Region 5 will spillover the border and create potential interference in these adjacent regions.

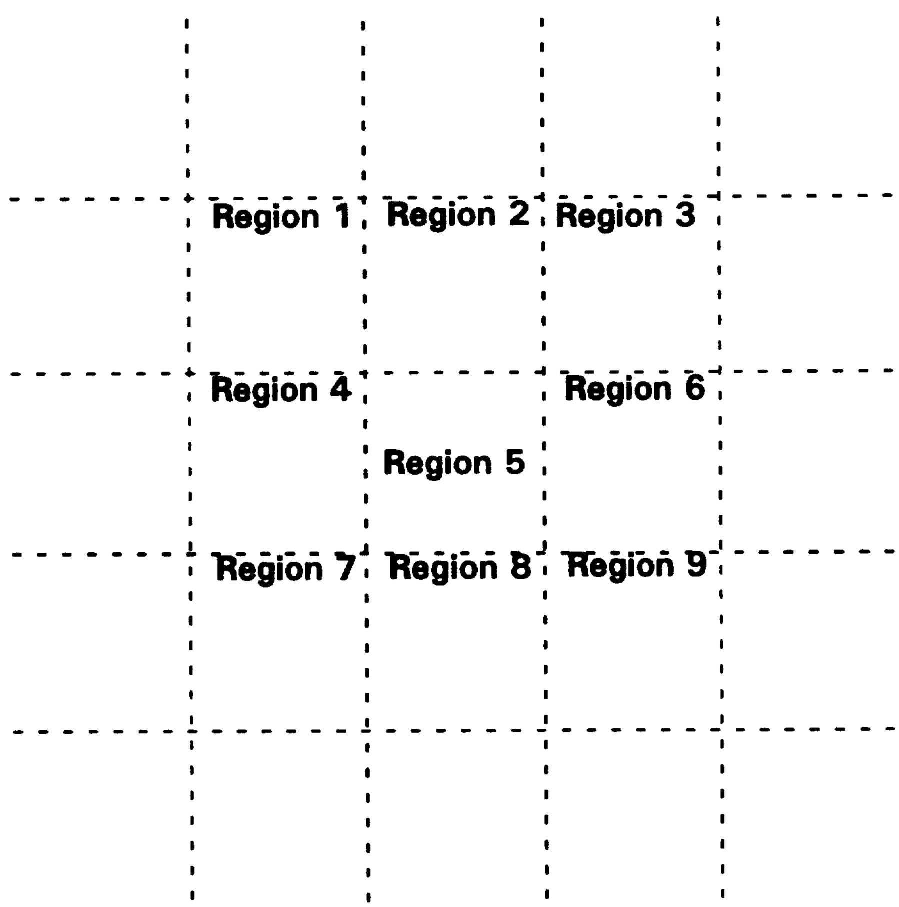

Figure 5

If one assumes that such transmissions create interference over relatively short ranges, then one sees the situation shown in Figure 6, where the shaded area shows the points where transmissions from inside Region 5 can cause interference outside Region 5 or where receivers inside Region 5 may be interfered with by transmitters operating outside Region 5. In this shaded area, technical decisions about PCS systems must be coordinated between the firms involved. In all cases, at least two firms are involved; near the corners, four firms are involved in each decision.

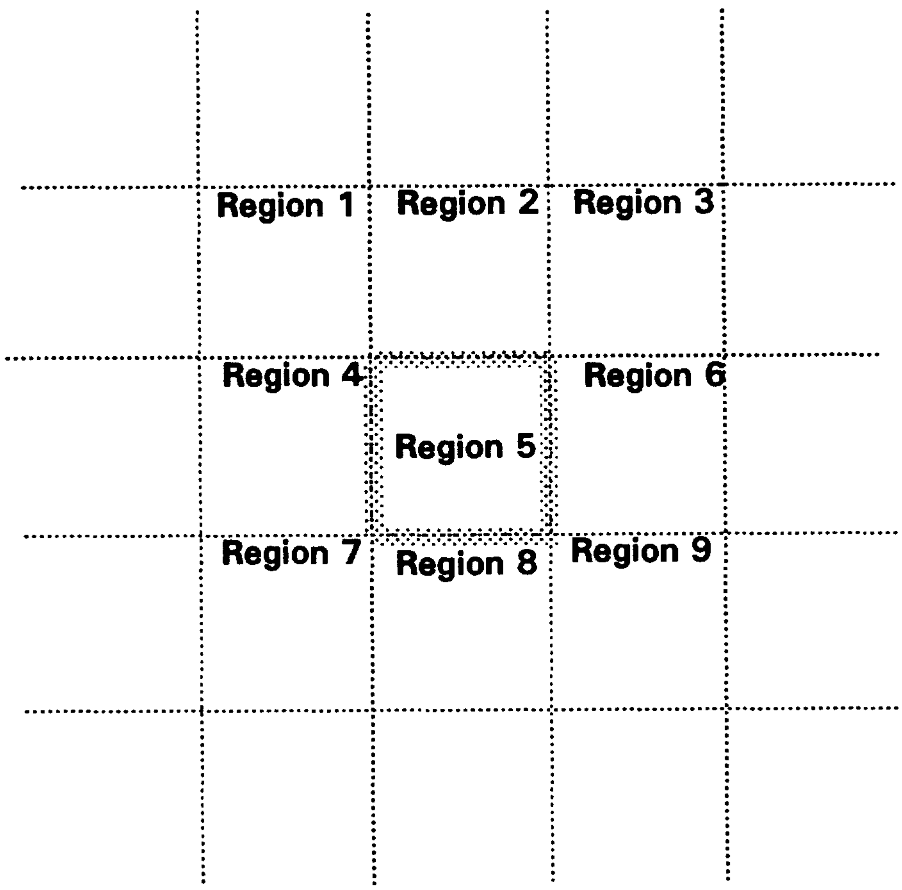

Figure 6

Figure 6 correctly represents the situation whenever the range of the interference is small. If the range of the interference is increased, then the situation shown in Figure 7 occurs where a high-powered transmitter located in the center of Region 5 generates interference into all adjacent regions.

Every point in the geographic service area is within interference range of points in other regions. Every decision that the Region 5 operator makes about transmitter site, antenna pattern, power, modulation, etc. interacts with the decisions of others. Substantial negotiation among rights holders is required.

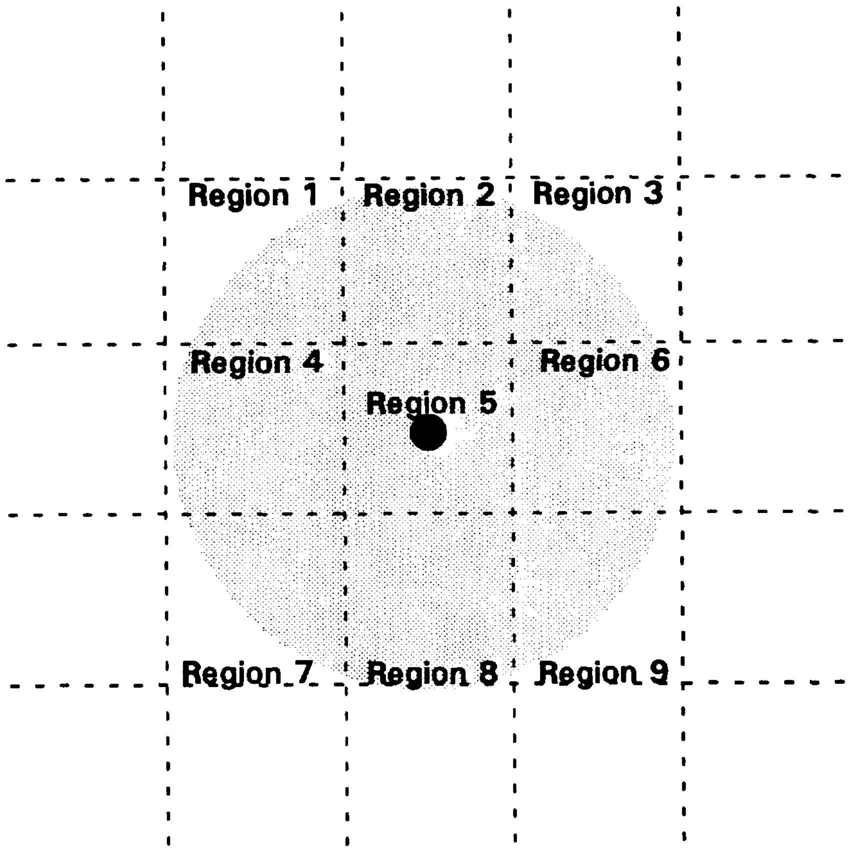

Figure 7

Notice also that, if one assumes that all license regions are identical squares, as the interference range becomes larger and larger, the number of other license regions affected by decisions in one region grows quadratically. For instance, assuming a grid of equal square regions, if the interference range is equal to the length of a side of the region, then a single decision by one operator may affect the operators in eight other regions. If the interference range is twice the length of a side of a region, then one technical decision has the potential to affect operators in at least twenty other regions.

This explosive growth of interference effects and coordination requirements is probably one of the reasons that cellular-like area licenses were not used for earlier radio technologies. For example, AM stations can create skywave interference hundreds of miles away. The FCC's rules require a co-channel separation of up to 220 miles between television stations[22] with a corresponding value of R of about 110 miles. If individuals had been given cellular-like area licenses but permitted to use technologies with the interference characteristics of television, then either the regions would have to have been enormous or every decision about spectrum use would have to have been coordinated with many rights holders. The first alternative, broad area licenses, might have led to unacceptable concentration in broadcasting. The second alternative, negotiations with dozens of licensees in order to coordinate operations, would appear to impose excessive and unnecessary transaction costs. Hence, the choice by the regulators to divide up the band into specific packages (the table of allotments) and to permit people to apply for the individual, predesignated license rights.

Clearly, one can eliminate any consideration of rights packages where the region size is small relative to the interference range. Notice that the Commission appears to have already accepted this view. It put forward four different service area proposals. From smallest to largest, they ranged from 487 "Basic Trading Areas" to 194 LATAs to 47 "Major Trading Areas" to a single nationwide license. All of these alternatives foresee regions that are large compared to the expected interference radius of PCS systems.

Let us examine the implications of such coordination regions in more detail. Consider for the moment, a square PCS license region as shown in the diagram below.

[22] See 47 CFR 76.610 (b).

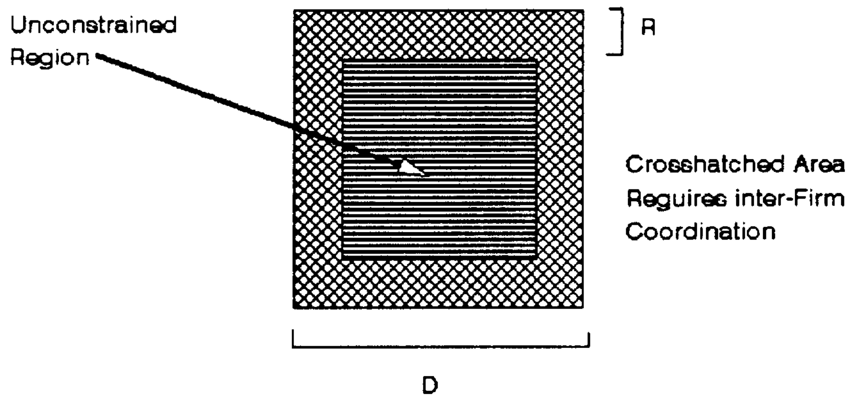

Figure 8

where:

D is the length of a side of the region; and

R is the distance from the edge where the licensee must take into account the presence of the boundary in day-to-day planning.

For cellular-like technologies, R lies in the range of two to four cell radii.[23] If the operator is considering an operation at a cell-site located at a distance more than R from the boundary, the operator need not worry about interference to neighboring systems or interference from neighboring systems. For the time being leave R as a variable, but assume that 2R is less than D -- that one does not have to worry about interference from

[23] This particular value of R comes from the nature of analog FM modulation. Digital and spread-spectrum systems are more robust and may support smaller values of R.

regions that are not adjacent. Later I will discuss the specific values of R in miles that might be appropriate for the PCS service.

With the assumption that R is small relative to D, points near the center of the region are sufficiently far away from the boundary that the licensee can deploy technology without the necessity of coordinating action with other license holders. There is still an area near the edge of the region where the system operator must take into account interference to and from the adjoining system.

One can define a measure of efficiency which is the ratio of the area where the licensee has such freedom to the total area covered by the license. Again, considering square regions of Side D and coordination distances of R where $2R < D$, the fraction of the total area of the region which does not require any direct[24] coordination is given by:

$$Efficiency = \left(\frac{D-2\times R}{D}\right)^2$$

[24] Note that coordination problems spread away from the region boundaries due to a daisy-chain effect. Decisions near the boundary affect system design decisions one or two cell diameters farther in. Those decisions affect decisions still further in, etc.

The graph below plots this measure of efficiency as the ratio for increasing values of the ratio D/R.

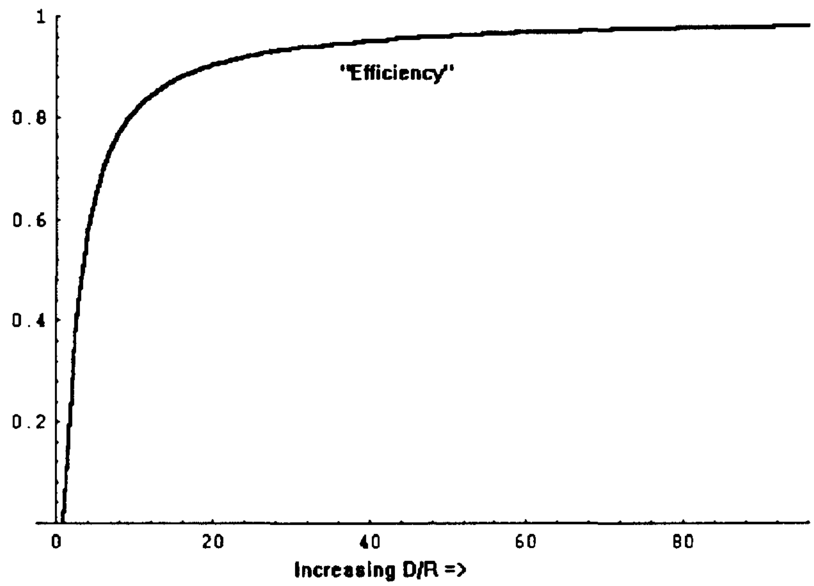

Figure 9 Efficiency Increase with Increasing D/R

This graph shows that this measure of efficiency increases as the size of region increases or, in a complementary fashion, as the interference radius declines.

This same approach can be applied to investigating, at least approximately, how this efficiency measure would vary with the number of PCS geographic service areas.

The land area of the coterminous U.S. is about 3,000,000 square miles.[25] If the U.S. is divided into *N* PCS geographic service areas, then we can approximate the side of a representative region as:

[25] One way to see this is to think of a rectangle 3,000 miles wide by 1,000 miles high. *The 1991 Statistical Abstract of the U.S.* lists the gross area (land and water) of the coterminous U.S. as 3,021,295 square miles (p. 7, Series 1).

$$\sqrt{\left(\frac{3{,}000{,}000}{N}\right)} \; Miles.$$

Using this approximation, one can use our previous equation to calculate the loss in this measure of efficiency as N increases from 1 to 47 to 194 to 487.

A key variable in this analysis is the interference radius or coordination distance. The reader may ask -- what are the specific implications of various values of the interference radius? For interference between two cellular systems, the coordination radius is about 30 miles. If one takes the view that PCS will be a personal service using relatively low-powered portable units, then the proper interference radius may be substantially smaller, say, 10 miles. Or conversely, if one takes the view that PCS will be a very flexible service and that it should be permissible for PCS operators to build some base stations with high towers and high transmit powers,[26] then the interference radius should be considerably larger, say, 50 miles. Note that the Commission has proposed a coordination distance of 125 miles between PCS base stations and existing co-channel and adjacent channel microwave systems. Larger coordination distances (up to 264 miles) have been proposed should PCS systems be allowed to operate at powers greater than 10 watts or antenna heights above 90 meters.

Below, I have redone the "efficiency" calculation in terms of relative transactions costs. For any assumptions on coordination distance and number of PCS license regions, one can calculate the fraction of the total land area of the United States where coordination will be required. Further assume that the transactions costs associated with such coordination are

[26] One can imagine an asymmetric data service designed to distribute electronic mail and other texts to low-powered personal portable workstations. Such a service might well employ high-powered transmitters and tall antennas to cover the less densely populated regions of the service area.

proportional to the area where coordination is required.[27] Then transactions costs increase as the number of regions increases or as the coordination distance increases. Figure 10 shows how relative transactions costs vary with the number of regions and the coordination distance. In this figure the transactions costs associated with a ten-mile coordination distance and a nationwide license are assigned the value of one. Less favorable configurations show higher transactions costs. (The formula used does not consider double overlaps of coordination areas. Hence, once the region size falls below

[27] This assumption is probably conservative. As regions get smaller, it becomes more and more likely that a larger fraction of the region boundaries are in more populous areas where coordination is more difficult.

100 miles on a side (300 regions) for the fifty-mile coordination distance, coordination costs reach a maximum.)

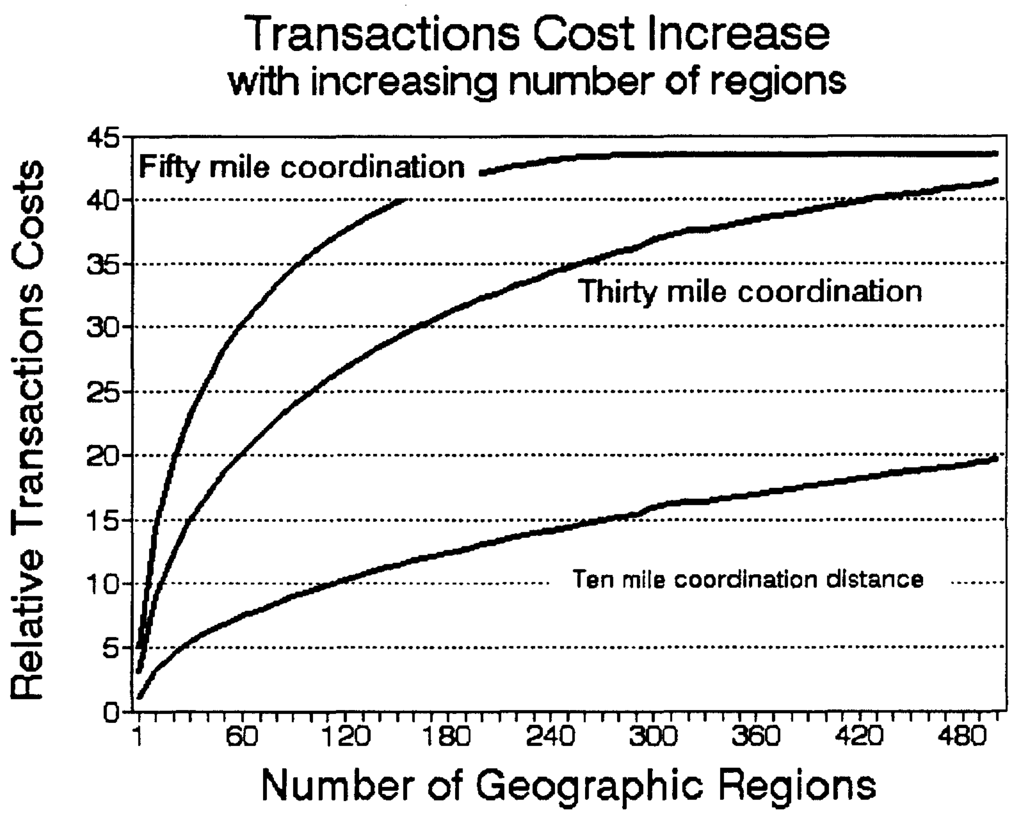

Figure 10

4.3 Discussion

Clearly, this measure of efficiency is imperfect. In many cases the boundaries between PCS service regions would be drawn in lightly populated areas where coordination between the firms in each of the two regions would be relatively simple. But the model treats interference management in high-density areas the same as in low-density areas.

Similarly, one could argue that the required interfirm coordination isn't that hard. The cellular industry has managed to do it for a number of years now, albeit with identical technologies on both sides of the boundary, and it does not seem to be a major problem for the cellular industry.

On the other side, one must point out that there is a real problem of potential interference across system boundaries. Thirty miles is a reasonable distance for considering such interference. One can imagine reasonable scenarios where interference effects would extend far beyond 30 miles.

While coordination has not been a major problem in cellular, that problem has been limited by many factors:

- The pattern of regionalization that has developed in cellular has removed many of the potential interfirm service area boundaries.[28]

- All cellular firms have, until very recently, used the same technology (AMPS), consequently potential interference has been symmetric between the two firms.

- While cellular has grown rapidly, the absolute levels of subscribership have been low until quite recently. Even now cellular subscribership levels are below those projected for PCS or for cellular in the future.

- Cellular service has been provided primarily to mobile units mounted in vehicles. Consequently, heavy usage near intersystem boundaries has been limited to major highways. The situation might have been quite different if cellular could have been used for fixed service analogous to BETRS.

Thirty miles is probably a reasonable distance for the interference radius when considering PCS services. The proposed rules in the NPRM would allow a system operator to install a 2 equal watt (EIRP) radiator about 150 meters of the region boundary. Assume that the firm in the adjoining region was using a low-power PCS technology with the following characteristics:

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[28] For example, McCaw has a cluster of cellular systems in Florida. Many telephone companies control regional clusters of adjacent cellular systems -- effectively as much larger license areas.

- 10 mW base station transmissions,
- 1000 meter service range under free-space conditions, and
- a 10 dB required signal to interference ratio (with regard to the system located in the adjacent region).[29]

If one further assumes the worst case propagation law (free-space) for the interference from the adjacent system, then one determines that a portable at the edge of its service area could receive interference as far as 27 miles from the boundary.

Similarly, interference drops off sharply when the interfering transmitter is beyond the radio horizon. An antenna 90 meters above the ground is below the radio horizon for a portable unit four feet above the ground when the units are separated by more than 27 miles.[30]

Given the lack of a Commission-imposed technical standard, the wide range of possible technologies, the potential for use of PCS to offer service to fixed locations[31] (which may have elevated receive antennas with gain), and the market uncertainty, interference coordination across system geographic boundaries can be expected to be a significantly greater problem for PCS than for cellular. Reducing the impact of any negotiations over interference control is an important public policy concern. The analysis above shows that licensing a relatively small number of regions substantially reduces the geographic area where such negotiations are required. Put another way, licenses serving wide geographic areas substantially reduce the transactions costs associated with negotiations between adjacent systems.

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[29] These assumptions are close to the properties of the CT-2 system.

[30] This assumes an effective earth radius of K = 1.33. See *Reference Data for Radio Engineers*, Sixth Edition, Howard W. Samms & Co., p. 28-12.

[31] See NPRM at paragraph 30 where ancillary operations ancillary to mobile PCS services are proposed.

5 Concluding Comments

PCS licenses can vary in both bandwidth and geographic area. The NPRM asked about the choice of dividing 90 MHz of PCS spectrum among three, four, or five licensees. The principle insight a technologist can offer on this decision is that, at any given level of a firm's traffic, a firm with access to more spectrum will probably be able to provide service to consumers at lower cost than a firm with access to less spectrum. The specific tradeoffs depend on the ratio of the cost of radios (required in direct proportion to usage) and the fixed costs of cells (which decline with increases in available bandwidth). The queuing efficiency arguments that were important for cellular do not appear to be important today -- over the range of three to five PCS systems considered in the NPRM.

In contrast, consideration of technological issues provides substantial insights into the choice of geographical service regions. Here, the answer is the larger, the better. In particular, nationwide licenses substantially ease the enormously difficult standards choice problem, allow for the efficient provision of roaming service, and facilitate agreement on international roaming. Nationwide licenses also remove intraband coordination activities between firms. This allows the licensee to exploit the proposed technological flexibility to a degree that would be impossible with smaller license areas.

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Prior to joining NERA, Dr. Jackson was a co-founder of the telecommunications consulting firm of Shooshan & Jackson Inc. In earlier employment, Dr. Jackson was staff engineer for the Communications Subcommittee of the U.S. House of Representatives and was on the staff of the Federal Communications Commission. He has also worked as a digital designer and computer programmer.

Dr. Jackson has served as an expert witness in litigation on computer services and software and has testified before several state utility commissions.

He has authored or co-authored numerous studies on public policy issues in telecommunications and has testified before Congress on issues of technology and telecommunications policy. Over the last several years, he has also directed or participated in projects in acquisition analysis, market planning and product pricing. He has written for both professional journals and the popular press with articles appearing in publications ranging from *The IEEE Transactions on Computers* to *Scientific American* to *The St. Petersburg Times*. He holds a U.S. patent on an alarm signaling system.

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	COMMUNICATIONS SUBCOMMITTEE, U.S. HOUSE OF REPRESENTATIVES--Washington, D.C.
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1973-1976	Consultant. Worked on implementation of digital communication systems over dispersive channels.
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1971-1973	Research and Teaching Assistant.
	SIGNATRON--Lexington, Massachusetts
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PROFESSIONAL ACTIVITIES

Member, Sigma XI, Institute of Electrical and Electronics Engineers (IEEE), IEEE Computer Society, IEEE Communications Society, IEEE Information Theory Group, American Association for the Advancement of Science, and International Telecommunications Society.

From 1987-88, served on Board of Directors of Telecommunications Policy and Research Conference. Chairman of Board 1988.

Chairman, IS/WP1 (Policy and Regulation) of the FCC's Advisory Committee on Advanced Television.

Executive Committee Member, University of Florida's Public Utility Research Center (PURC).

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"LEC Gateways: Provision of Audio, Video and Text Services in the U.S." Presented to the National Economic Research Associates, Inc., Telecommunications in a Competitive Environment Seminar. Scottsdale, Arizona. April 15, 1989. Also presented to the 8th Annual ITS International Conference. Venice, Italy. March 1990.

"The Evolution of Access." Presented to the Seventeenth Annual Telecommunications Policy Research Conference. Airlie, Virginia. October 1-3, 1989.

"Open Network Architecture: Definition, Benefits and Costs, Impact on Industry Structure and Performance." Speech presented to the Nineteenth Annual Williamsburg Conference. Williamsburg, Virginia. December 7-9, 1987.

With Harry M. Shooshan III, Jeffrey H. Rohlfs and Susan W. Leisner. "The Negative Effects of Tax Reform on the Telephone Industry: Making Up the $15 Billion Difference." Presented to the Fifteenth Annual Telecommunications Policy Research Conference. Airlie, Virginia. September 27-30, 1987.

"Is Bypass Still A Threat Today?" Speech presented to the Telecommunications Policy In a Competitive Environment Seminar. Scottsdale, Arizona. March 4-7, 1987.

With Jeffrey H. Rohlfs. "Improving the Economic Efficiency of NTS Cost Recovery." Presented to the Fifth Biennial Regulatory Information Conference. Columbus, Ohio. September 3-5, 1986.

With Jeffrey H. Rohlfs. "Improving the Economic Efficiency of Interstate Access Charges." Presented to the Fourteenth Annual Telecommunications Policy Research Conference. Airlie, Virginia. April 27-30, 1986.

Remarks presented to The Council of State Planning Agencies. Lincoln, Nebraska. October 20-21, 1985.

"Cable and Public Utility Regulation." Speech prepared for the Reason Foundation Conference on Public Utilities. Washington, D.C. September 9, 1983.

"Technology Options In Enhanced Services: Twisted Pair to Videodiscs." Comments in *Enhanced Services*. NCTA Executive Seminar Series. National Cable Television Association. Washington, D.C. 1981.

"The Political Climate for Communications: Gusty Winds from All Directions." Presented to the Energy Bureau, Inc. Washington, D.C. December 10-11, 1981.

"Electronic Mail: What Is It? What Might It Be?" Presented to the 1976 Telecommunications Policy Research Conference. Airlie, Virginia. 1976.

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Dr. Pickholtz is President of Telecommunications Associates, a research and consulting firm specializing in Communication System disciplines. He was elected a member of the Cosmos Club and a fellow of the Washington Academy of Sciences in 1986. In 1984, Dr. Pickholtz received the IEEE centennial medal. In 1987, he was elected as Vice President, and in 1990 and 1991 as President of the IEEE Communications Society.